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A Split-Function Lattice for Stochastic Cooling

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DISCLAIMER

A SPLIT-FUNCTION LATTICE FOR STOCHASTIC COOLING *

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Abstract

Lattice for a 3-GeV cooler ring with split functions is presented. The ring consists of two half-rings of different properties: in one half-ring, the phase-slip factor is near-zero; in the other half-ring, the phase-slip factor is large. The near-zero phase slip minimizes the "bad mixing" between the stochastic-cooling pick-ups and kickers, while the high phase slip maximizes the "good mixing" between the kickers and the next-turn pick-ups.

INTRODUCTION

In Ref. [1] we reported the lattice design for rapid-cycling synchrotrons used to accelerate high-intensity proton beams to energy of tens of GeV for secondary beam production. After primary beam collision with a target, the secondary beam can be collected, cooled, accelerated or decelerated by ancillary synchrotrons (or cooler rings) for various applications [2, 3, 4].

To increase the efficiency of stochastic cooling in the cooler ring, the phase-slip factor between the cooling pick-ups and kickers shall be small to minimize the "bad mixing", and the phase-slip factor between the kickers and the next-turn pick-ups should be large to enhance the "good mixing" [5, 6]. In this paper, we present the preliminary lattice design for a 3-GeV cooler ring with split functions. The ring consists of two half-rings of different properties: in one half-ring, the phase-slip factor is near-zero; in the other half-ring, the phase-slip factor is large.

LATTICE LAYOUT AND FUNCTIONS

Two different lattice structures are adopted for each half of the split-function ring. We choose a normal FODO structure to achieve near-zero phase-slip factor in one half-ring, and choose Flexible Momentum Compaction (FMC) lattice to achieve large phase-slip factor in the other half-ring [7, 8, 9, 10]. The magnet layout of the ring is shown in Figure 1.

FMC Module Structure for Large Phase Slip

We use the FMC lattice to realize a small momentum compaction factor α_p, so that the absolute value $|\eta|$ of the phase-slip factor

$$\eta = \alpha_p - \frac{1}{\gamma^2} \tag{1}$$

is large. Here, γ is the Lorentz factor. For protons or anti-protons of 3-GeV kinetic energy, $\gamma = 4.2$.

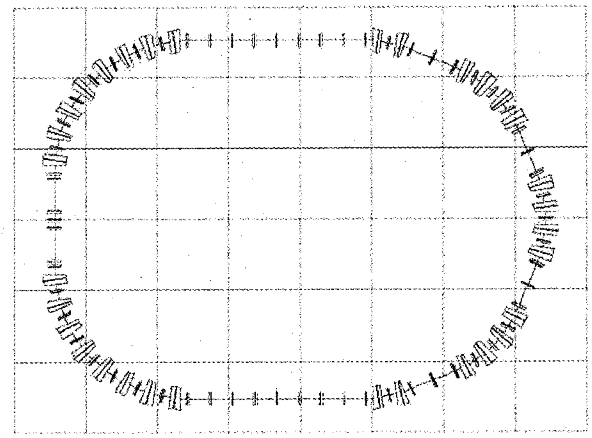

Figure 1: Main magnet layout of the cooler ring.

A FMC lattice without negative bending requires negative dispersion at locations of bending dipoles. Figure 2 shows the lattice module consisting of three FODO cells with missing dipole in the middle cell. The horizontal phase-advance of about 90° per cell excites dispersion oscillation so that high dispersion occurs at locations of missing dipoles.

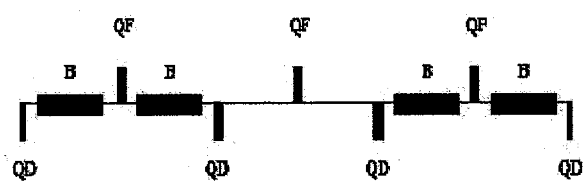

Figure 2: FMC module with missing dipoles.

The half-ring of large phase-slip factor is designed by using the modules shown in Figure 2. The lattice consists of four modules, as shown in the right-hand-side of Figure 1. The horizontal phase advance is near but not equal to 270° across each three-cell module. The horizontal phase advance across the four-module arc is exactly 6π, so that the dispersion is completely suppressed outside of the arc.

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The momentum compaction factor can be easily adjusted by varying the strength of the quadrupole families in the arc. The momentum compaction across this 180° bend is 0.001. The phase-slip factor of the lattice is −0.055. The lattice function is shown in the Figure 3.

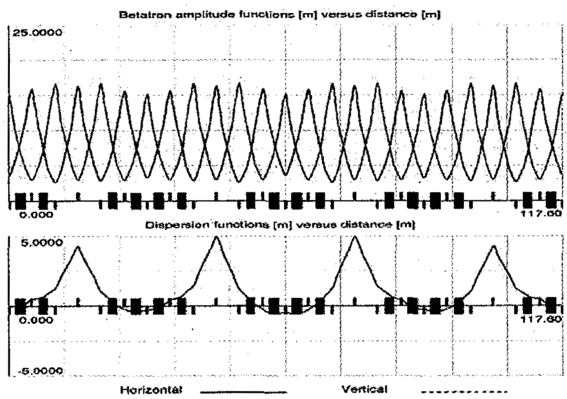

Figure 3: Lattice functions of the large phase-slip half-ring with FMC modules (blue in top chart: β_H; red in top chart: β_V; bottom chart: D_p).

Normal FODO Structure for Small Phase Slip

As shown in the Figure 1, the left-hand-side of the cooler ring contains two bending arcs, each containing four FODO cells. The horizontal phase advance is exactly 2π across each of these normal arcs. Two arcs are connected by a dispersion-free straight section with triplet-quadrupole focusing structure. By tuning the strength of the quadrupole families and the distance between the magnets, the momentum compaction across this 180° bend is adjusted to 0.0562 so that the phase-slip factor of the lattice is small ($\eta = 0.0005$). The lattice function is shown in Figure 4.

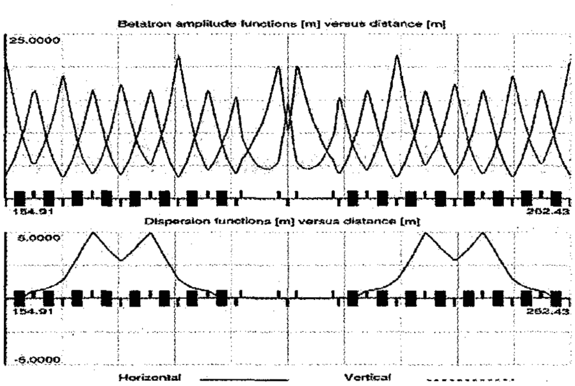

Figure 4: Lattice functions of part of the small phase-slip half-ring with FODO and triplet structure (blue in top chart: β_H; red in top chart: β_V; bottom chart: D_p).

Main Parameters

Corresponding to the kinetic energy of the 3 GeV beam and the circumference of the main accelerator, the circumference of the cooler ring is selected to be 299.7 m [1]. The maximum β-function is less than 23 m. The maximum dispersion is about 5 m. The lattice super-periodicity is 1. The focusing structures in the straight sections are FODO and triplet, providing drift spaces with uninterrupted length up to about 4 m to accommodate stochastic-cooling pickups and kickers, electron cooling, injection, extraction, and RF systems. Figure 5 shows the lattice function of entire ring. Table 1 gives the primary parameters.

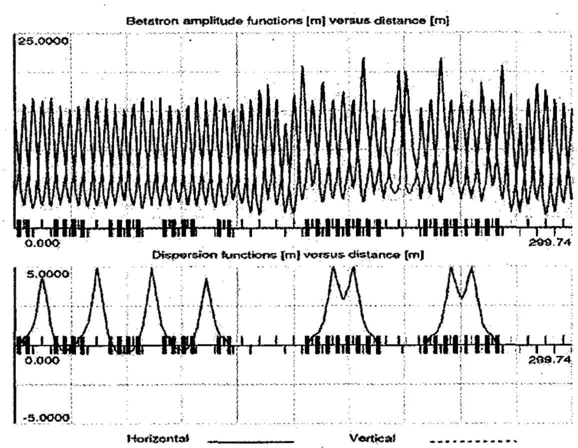

Figure 5: Lattice function of the entire cooler ring (blue in top chart: β_H; red in top chart: β_V; bottom chart: D_p).

Table 1: Primary parameters of the cooler ring.

Ion type	proton/anti-proton
Beam kinetic energy [GeV]	3
Ring circumference [m]	299.7
Lattice type - small phase-slip half	FODO/triplet
Lattice type - large phase-slip half	FMC
Uninterrupted drift length in straight [m]	< 4.2
Nominal betatron tune (H)	7.30
Nominal betatron tune (V)	7.34
Transition energy, γ_T	31.6
Natural chromaticity (H)	−8.7
Natural chromaticity (V)	−9.5
Maximum dispersion [m]	4.94
Momentum compaction factor	0.022

SUMMARY

Based on the Flexible Momentum Compaction lattice modules and FODO/triplet structures, we designed a split-function lattice for 3-GeV proton or anti-proton beams. As an example to facilitate stochastic cooling with high efficiency, we set the phase-slip factor between the cooling pick-ups and kickers to near-zero (0.0005) to minimize the "bad mixing", and set the phase-slip factor between the kickers and the next-turn pick-ups to -0.055 to enhance the "good mixing".

In the case that the pick-ups or kickers need to be placed in high-dispersion locations, drifted spaces of dispersion near 5 m are available. The strengths of the quadrupole families may be adjusted to again realize the split-function features.

The lattice study presented is preliminary. Detailed work including dynamic-aperture evaluation is yet to be performed.

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